Claims

1. A total-reflection x-ray fluorescence apparatus comprising:

    an x-ray source for providing x-rays;

    a doubly-curved x-ray optic for diffracting the x-rays;

    a surface onto which at least some of the diffracted x-rays are directed; and

    an x-ray detector for detecting resultant x-ray fluorescence emitted by any foreign matter present on the surface.

Sub. B1

2. An apparatus as recited in claim 1 wherein the doubly-curved x-ray optic also focuses the x-rays on to the surface.

3. An apparatus as recited in claim 1 wherein the doubly-curved optic is a crystal or multi-layer optic.

Sub B2

3 ~~4~~. An apparatus as recited in claim 1 wherein the doubly-curved x-ray optic has one or more atomic planes.

4 ~~5~~. An apparatus as recited in claim 3 ~~4~~ wherein the atomic planes are curved to form a toroidal, ellipsoidal, spherical, parabolic, or hyperbolic shape.

6. An apparatus as recited in claim 1, further comprising one or more apertures for limiting a convergent angle of the diffracted x-rays, wherein the convergent angle comprises the angle subtending the upper and lower extents of the diffracted x-rays.

Sub D2

Sub. B3 7. An apparatus as recited in claim 6 wherein the one or more apertures are positioned at at least one of before the x-ray optic and after the x-ray optic.

6 ~~8.~~ An apparatus as recited in claim ~~6,~~ 5 wherein the one or more apertures comprise an elongated slot.

7 ~~9.~~ An apparatus as recited in claim ~~6~~ 5, wherein the one or more apertures produce a convergent angle for the diffracted x-rays which is less than the critical angle for the total reflection of the x-rays from the surface for the wavelength of the x-rays.

9 ~~10.~~ An apparatus as recited in claim 1, wherein the doubly-curved x-ray optic employs Bragg's law in diffracting the x-rays .

10 ~~11.~~ An apparatus as recited in claim 1, further comprising an analyzer for analyzing the x-ray fluorescence detected by the detector.

11 ~~12.~~ An apparatus as recited in claim 1, wherein the surface is an optical reflection surface.

12 ~~13.~~ An apparatus as recited in claim 1, wherein the surface is a surface of a semi-conductor wafer.

Sub B3 14. An apparatus as recited in claim 1, wherein the locations of the doubly-curved x-ray optic, x-ray source, and point of impingement upon the surface define an optical circle of radius R wherein the doubly-curved x-ray optic has an optic surface of radius 2R and one or more atomic planes essentially parallel with the optic surface.

20 ~~15.~~ An apparatus as in claim ~~14,~~ 19 wherein the doubly-curved x-ray optic provides one of symmetric or asymmetric Bragg diffraction.

21 16. An apparatus as recited in claim ~~14~~ 19, wherein the atomic planes are curved to form a toroidal, ellipsoidal, spherical, parabolic, or hyperbolic shape.

22 ~~17.~~ An apparatus as in claim ~~14~~ 19, wherein the doubly-curved x-ray optic has a transverse plane perpendicular to the optic circle wherein in the transverse plane the atomic planes are circular.

Sub. 34

18. A method for detecting presence of foreign matter on a surface using a doubly-curved x-ray optic, comprising:

providing a source of x-rays;

diffracting at least some of the x-rays using a doubly-curved x-ray optic and impinging the diffracted x-rays upon the surface;

detecting flourescent x-rays responsive to the impingement from any foreign matter present on the surface.

19. A method as recited in claim 18, wherein the diffracting focuses the at least some x-rays onto the surface.

20. A method as recited in claim 18, further comprising impinging the diffracted x-rays upon the surface so that the x-rays are totally-reflected from the surface with little or no x-ray scatter.

34 ~~21.~~ A method as recited in claim ~~18~~ 33, further comprising exciting foreign matter present on the surface with the diffracted x-rays so that the foreign matter emits the fluorescent x-rays.

~~22.~~ A method as recited in claim 18, further comprising passing the x-rays through at least one aperture to limit the convergent angle of the x-rays, wherein the convergent angle comprises the angle subtending the upper and lower extents of the diffracted x-rays.

23. A method as recited in claim 22, wherein the passing through at least one aperture is practiced at at least one of: before the x-ray optic or after the x-ray optic.

37 ~~24.~~ A method as recited in claim 33 ~~18,~~ further comprising analyzing the detected x-rays to determine the nature of the foreign matter.

25. An apparatus for diffracting x-rays comprising:

an x-ray source and image defining an optic circle of radius R;

an x-ray optic having a surface and a plurality of atomic planes having a radius R_P which intersect the surface at an angle α;

wherein the radius of the atomic planes R_P is defined by the equation

$$R_P = 2R \cos \alpha.$$

26. An apparatus as recited in claim 25, wherein the angle α is grater than 0° and less than 90°.

27. An apparatus as recited in claim 26, wherein the angle α is greater than 0° and less than 20°.

28. An apparatus as recited in claim 25, wherein the optic is a doubly-curved optic.

29. An apparatus as recited in claim 28, wherein the doubly-curved optic is curved to a toroidal, ellipsoidal, spherical, parabolic, or hyperbolic in shape.

~~30.~~ An apparatus as recited in claim 28, wherein the doubly-curved optic exhibits asymmetric Bragg diffraction.

~~31.~~ An apparatus as recited in claim 28, wherein the doubly-curved x-ray optic also focuses the x-rays on to the surface.

32. A total-reflection x-ray fluorescence apparatus comprising:

an x-ray source for providing x-rays;

a doubly-curved x-ray optic for diffracting the x-rays having a surface and a plurality of atomic planes of radius R_P which intersect the surface at an angle α;

a surface onto which at least some of the diffracted x-rays are directed; and

an x-ray detector for detecting resultant x-ray fluorescence emitted by foreign matter present on the surface;

wherein the radius of the atomic planes R_P of the doubly-curved optic is defined by the equation $R_P = 2R \cos \alpha$.

33. An apparatus as recited in claim 32, wherein the angle α is grater than 0° and less than 90°.

34. An apparatus as recited in claim 33, wherein the ~~angle α~~ is greater than 0° and less than 20°.

35. An apparatus as recited in claim 32, wherein the optic is a doubly-curved optic.

36. An apparatus as recited in claim 35, wherein the doubly-curved optic is curved to a toroidal, ellipsoidal, spherical, parabolic, or hyperbolic in shape.

37. An apparatus as recited in claim 32, wherein the doubly-curved optic exhibits asymmetric Bragg diffraction.

38. An apparatus as recited in claim 32, wherein the doubly-curved x-ray optic also focuses the x-rays on to the surface.

39. An apparatus as in claim 2, wherein the doubly-curved x-ray optic focuses to a footprint on the surface, the foot print having a largest dimension less than 1 mm.

40. An apparatus as in claim 39, wherein the doubly-curved x-ray optic focuses to a footprint on the surface, the foot print having a largest dimension less than 500 microns.